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Montana. Board of Water Well Contractors Well developments

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WELL DEVELOPMENTS

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This newsletter will be devoted almost entirely to the following article on iron and iron bacteria in groundwater. Because the public and the well drilling industry are more aware of the problems caused by iron bacteria, the Board of Water Well Contractors felt this article would be appropriate. It is adapted from an article written by Joseph J. Donovan, a hydrogeologist with the Montana Bureau of Mines and Geology in Billings, Montana.

The Nature of the Problem

Chemistry of Iron and Manganese in Groundwater

Iron and manganese are common constituents of many different types of rocks and sediments, some of which are aquifers. Groundwater tends to develop chemical characteristics which indicate the chemical composition of the aquifer through which it passes; this is especially true if the aquifer is rich in easily-soluble salts or minerals. Many types of rocks found in Montana contain iron-rich minerals, including sandstone, shales, some coal beds, igneous rocks such as granite, and volcanic rocks such as basalt.

A mineral source of iron and manganese is not the only reason that iron in groundwater reaches high levels. The chemical environment within the aquifer, primarily oxidation level and pH of the water, strongly influences iron concentrations. The common mineral species that control iron solubility include iron carbonate (siderite), iron sulfide (greigite, pyrite), and iron oxide or hydroxide (hematite, amorphous iron hydroxide). Most groundwater is impoverished in oxygen and of near-neutral pH. Under these conditions and in the presence of soluble iron minerals, dissolved ferrous (reduced) iron concentrations can rise to high values — 5 milligrams per liter (mg/L), or parts per million (ppm), is not uncommon. For comparison, above about 0.3 mg/L (the recommended EPA secondary drinking water limit), water contains just enough iron to begin to cause fouling problems in normal use. Dissolved iron concentrations of over 0.3 mg/L, therefore, could be termed as "high". Concentrations over 3.0 mg/L would cause noticeable fouling that would discourage its use in household supplies unless treatment were performed; such water could be termed "very high" in iron.

Iron at high concentrations entering a water well is in the reduced (ferrous) state, dissolved, colorless, and not visible to the eye. When water is pumped from a well — into cisterns, sinks, toilets, lawn sprinklers, and laundries — it enters an oxygen-rich environment very different from that within the aquifer, and the ferrous iron is rapidly converted to the oxidized (ferric) state. The solubility of ferric iron is extremely low (less than 0.2 mg/L) under neutral pH conditions, and upon oxidation it rapidly precipitates from solution as a fine, yellow- or red-brown hydroxide deposit. In standing water, this precipitate will settle from suspension and accumulate at the bottom. The hydroxides have a high surface charge and adsorb and bond firmly to porcelain, siding, and many other materials. The precipitation process is normally fairly rapid, proceeding to completion within a few hours. Oxidizing agents, such as chlorine, permanganate, oxygen gas, and air itself, accelerate the precipitation process.

Manganese is a common trace metal in iron-rich minerals because its chemical nature is similar to that of iron. Manganese can occur in the reduced state up to concentrations over 1 mg/L in unoxidized water of near-neutral pH. When oxidized, it will precipitate as manganic oxide, forming a black precipitate. Manganese occurs at generally lower concentrations than iron and precipitates as an oxide with greater difficulty. The EPA secondary drinking water limit for manganese is 0.05 mg/L, for aesthetic reasons as for iron. A very high value for manganese in groundwater would be > 0.5 mg/L. Well water with high levels of iron will commonly, but not always, also exhibit high levels of manganese. Manganese is more difficult to remove by water treatment, because it is oxidized more slowly.

Some formations in Montana that are especially iron-rich include: sandstone of Cretaceous (Eagle, Judith River, and Kootenai formations) and Tertiary (Fort Union Formation) age; and volcanic deposits, particularly in the mountainous portions of the state. The physical erosion performed by glaciers and rivers breaks up bedrock materials and makes them more susceptible to chemical dissolution; for this reason, alluvial and glacial sediments derived from iron-rich bedrock formations contain aquifers with some of the highest iron concentrations in the state.

Based on statewide water chemistry data, a simple classification (Table 1) describes aquifer susceptibility to iron problems. Glacial and alluvial aquifers (Category A) are highly

susceptible to iron problems over many areas of the state. Much older and often deeper bedrock aquifers, such as the Madison limestone and the Fox Hills and Hell Creek formations (Category C), are generally low in iron and good targets for development of a low-iron source. A number of sandstone aquifers extensively used in the Hi-Line area (Category B) can exhibit high iron, but in a lower percentage of wells than for the glacial and alluvial aquifers. Into which category does the aquifer you use fall?

Figure 1 is a map of the state upon which are plotted locations of domestic and stock wells known to have "very high iron" (> 3 mg/L; large circles) and those with "high iron" (> 0.3 mg/L; small circles). There are of course many more wells with iron; those plotted, perhaps only a few percent of the total, are those for which we have chemical data. The problem is essentially statewide, with major areas of concentration in the northern and northeastern parts of the state.

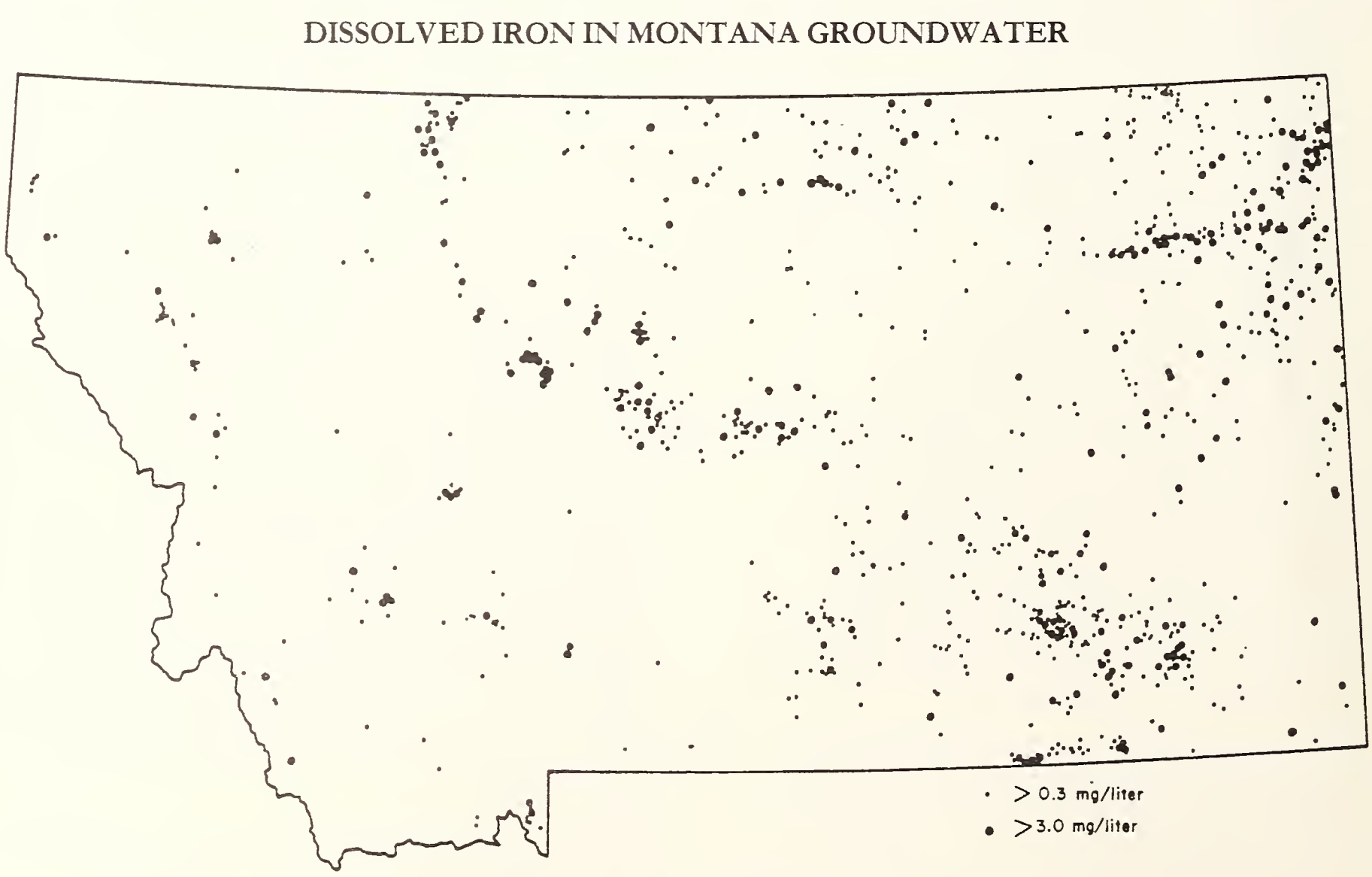
Table 1

Categories of susceptibility to high iron concentrations in some common Montana aquifers

Category	Susceptibility to Iron	Aquifer Name (Geologic Age)
A	High	Glacial aquifers (Pleistocene) Alluvial Aquifers (Cenozoic)
B	Moderate	Fort Union Fm. (Tertiary) Judith River Fm. (Cretaceous) Eagle Fm. (Cretaceous) Kootenai Fm. (Cretaceous)
C	Low	Hell Creek Fm. (Cretaceous) Fox Hills Fm. (Cretaceous) Swift Fm. (Jurassic) Ellis Group (Jurassic) Amsden Group (Mississippian) Big Snowy Group (Mississippian) Madison Group (Mississippian)

Figure 1

Dissolved iron concentrations in Montana groundwater. Large circles indicate samples with "very high iron" (3.0 mg/L or more); small circles have "high iron" (0.3 mg/L or more), the EPA secondary limit.
Source: Ground Water Information Center.

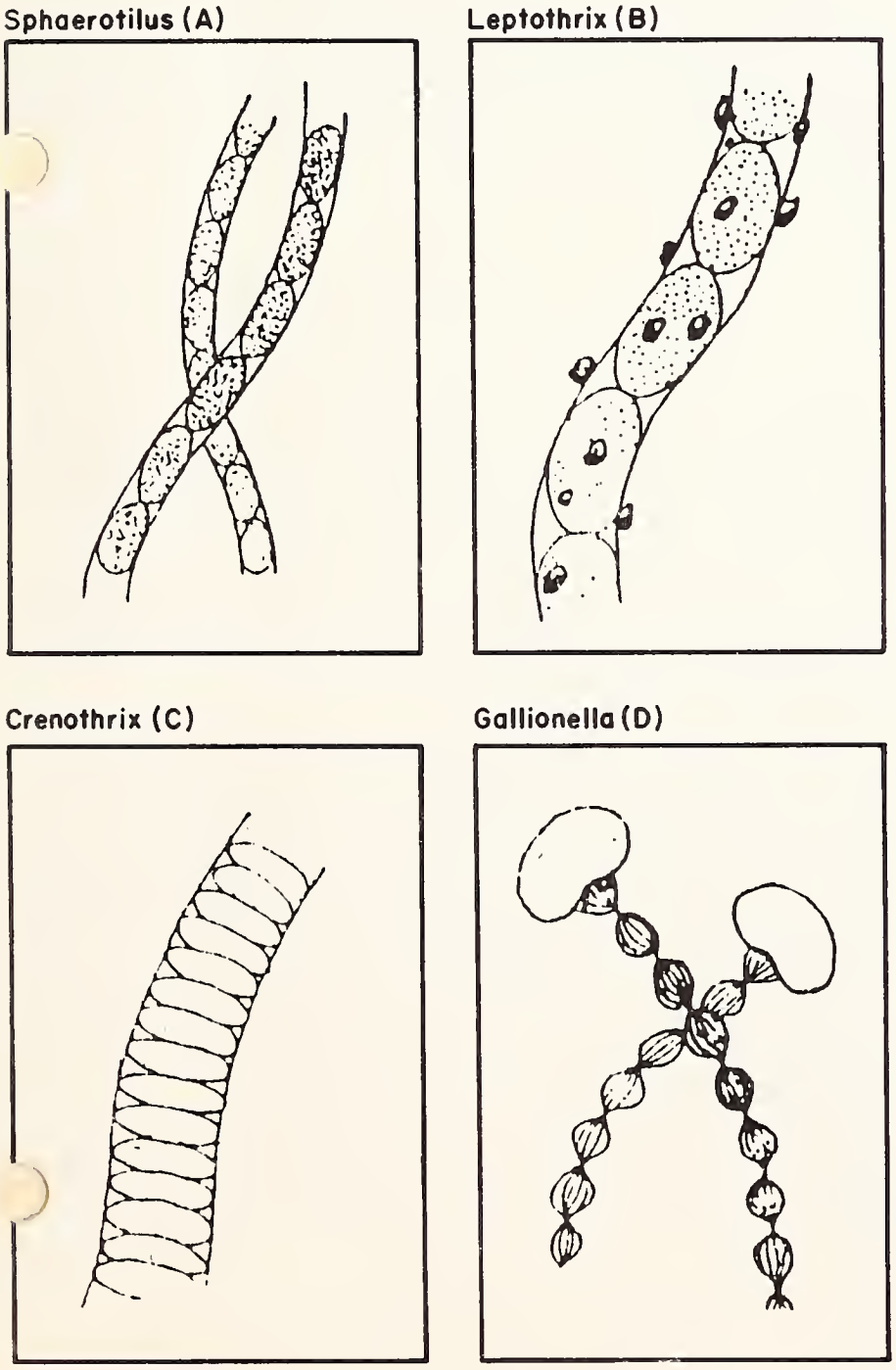


Iron Bacteria: The Hidden Hazard

"Iron bacteria" is the term loosely applied to a number of genera of water-borne bacteria that thrive in iron-rich groundwater. Water of at least 0.2 mg/L iron is required for their survival; some may actually use energy from the biologically-assisted oxidation of ferrous iron. All incorporate chemically-oxidized iron precipitates into their structure. The common iron bacterial groups are stalked forms (Gallionella); filamentous, sheathed forms (Crenothrix, Leptothrix); and single-celled, in some cases motile forms (Siderocapsa, Ochrobrium) (Figure 2). Naturally-occurring infestations normally include several species. All are dormant at temperatures below about 40° F; grow slowly at normal groundwater temperatures (45° to 60° F); and grow more rapidly at higher temperatures, up to temperatures of about 150° F, above which they die.

Figure 2

Morphological sketches of four common genera of iron bacteria found in water wells. Sphaerotilus (A), Leptothrix (B), and Crenothrix (C) are filamentous, sheathed forms; Gallionella (D) is a stalked form, marked by its characteristic bean-shaped cell.



It is not clearly understood how wells become infested with iron bacteria. These are common surface and soil bacterial forms, which some researchers believe are introduced by drilling equipment. The bacteria thrive in the well environment, where there is a high level of oxidation, suitable substrate for growth (well casing and pump), a heat source (the pump motor), and a steady influx of fresh nutrients in the groundwater gradually entering the well. Infestations normally begin at the well intake and spread upward to the distribution system and outward to the aquifer outside the well. They are killed by ultra violet light, and hence always are "hidden", down wells and in pipes, and difficult to see or detect.

The easiest way to see an iron bacterial infestation is to pull the pump of an affected well. The bacteria are red-brown (ochre) to pink in color and grow in layers, with a slimy, mucaceous sheath around the active outer surface. the color is due to incorporation of hydroxide precipitates into this sheath. They sorb firmly on substrate material and their armor of slime and hydroxide resists attack from many chemicals and disinfectants used to clean water wells. The bacteria themselves are soft and slimy, in contrast to the hard natural iron precipitates.

The bacteria do not pose a health hazard, but they can eventually make both well water and the well itself unusable. They commonly plug off the pump or well intake with their own mass and with iron oxide products they incorporate. If natural iron concentrations are high, the plugging can be accompanied by cementation and encrustation of iron. In general, the higher the iron concentration, the faster the plugging occurs. At advanced stages of infestation, corrosive sulfate-reducing bacteria co-inhabit the well with the iron bacteria, causing further damage to well casing and water quality from hydrogen sulfide gas produced. This gas is easily recognized by its "rotten egg" odor.

An iron bacterial infestation follows a series of phases taking from a few months up to several years, depending on how favorable conditions for the bacteria are. First, as the population grows, there is no visible indication of their presence except for a gradual loss in well efficiency, lowering the pumping water level of the well. Later, the water level in the well falls to the pump intake, causing it to "suck air" and allowing free access of oxygen to the production zone. By now, water may be discolored with iron and organic matter, and carry foul odors. Finally, well yield is reduced to well below its original amount, and the well must either be reclaimed or abandoned. There is often little visible sign of a growing infestation until it is quite advanced, by which time remedial measures are only partly effective or are effective for only short periods. Often when the well owner first senses that something is very wrong with the well, it is too late to reclaim it.

How common are such infestations? Probably very common. Data from the Ground Water Information Center in Butte (GWIC) suggests that 10-30% of all wells in the central and eastern portions of the state have iron concentrations over 0.3 mg/L. Studies done in Saskatchewan indicate that over 90% of wells producing iron-rich water in one area of the province are affected by iron bacteria. These bacteria are the rule, not the exception. If the well water has high iron, the well probably supports iron bacteria.

Solving the Iron Problem: Removal and Treatment

Two distinct problems are commonly associated with iron-rich groundwater: how to remove the high iron load, and how to control the iron bacteria.

Getting Rid of the Iron

One approach to eliminating the high iron load is to drill a new well to an iron-free aquifer. This is possible in some cases, but should only be attempted with care, planning, and a reasonable possibility of such a source existing within a reasonable drilling depth. Obtain information on other aquifers and their depth and water quality in your location from the Montana Bureau of Mines and Geology Ground Water Information Center. In most cases, however, iron-free aquifers will be either too deep or of higher mineral content than the shallower, high-iron aquifers. On the other hand, some sand and gravel aquifers shallower than 100 feet have very low iron.

A more widely applicable approach is to use water conditioning equipment to remove the iron load. This technology is both practical and affordable for residential-scale (< 15 gpm) applications. Three basic approaches to treating iron-rich water are:

- to oxidize ferrous iron to ferric using either chemical or air oxidation, followed by removal using pressure filtration
- to adsorb ferrous iron onto an ion exchange resin in a conventional water softener
- to maintain ferrous iron in a soluble form using chemical additives (sequestering agents)

The most effective removal systems are of the first type, although some water softeners may handle small iron loads (< 1 mg/L). For higher iron loads, use of a filter system designed specifically for iron is generally most effective.

Iron filters for domestic water supplies oxidize iron with either chemicals or air. Chemical filters use a strong oxidant — such as potassium permanganate or chlorine — and a sand or greensand filter material. Greensand-permanganate filters can also remove manganese if this is also high, as it is in some waters. Aeration filters use either a compressor or, in some recently developed systems, a passive Venturi valve to stream air into the water. Both require regular backflushing of the filter material to remove iron oxides, much as a water softener requires regeneration with salt. Filter capacity for household units are normally insufficient for lawn irrigation, which would require a separate non-filtered line or a water storage tank. Typical system costs range from $500-$1,500. Some units of both chemical and aeration types have been shown to be effective at iron concentrations in excess of 5 mg/L. Aeration-type filters are simpler to maintain and are generally adequate to remove high iron (but not manganese) loads.

Sequestering solutions are concentrated polyphosphate solutions, injected into a water line using a chemical feed pump to keep the iron in a soluble (ferrous) state, and not allow it to precipitate. The polyphosohate molecule "binds" itself tightly to the ferrous iron and prevents it from being oxidized. No iron is removed from the water, but the water remains clear and the iron in solution. Different products have different solution chemistry and various durations of effectiveness. There is some potential for nutrient loadings in drain water, which could be of concern in areas adjacent to lakes and streams. There is also the risk of under- or over-application of chemicals. Antisiphon devices and check valves must normally be used to prevent concentrated feed solution from entering the well inadvertently. The major attraction of polyphosphates is low cost: only a feed pump and a regular supply of chemicals are required. However, long-term effectiveness at iron concentrations over 3 mg/L is not claimed by most vendors of polyphosphate products. Water users with severe iron loadings may in many cases be better off with a filter system of good design.

Domestic-scale iron treatment may be a very good alternative if the existing well is in good working order and the quality of the water it produces acceptable — low in total dissolved solids, hardness, and nitrates. In such a case it is probably less costly to treat than to re-drill. A water quality analysis should be performed before you select a unit, and if possible, manufacturer's claims should be verified by seeing an existing successful installation treating water of similar quality to yours. Table 2 gives a partial list of currently available iron treatment products, including a representative list of the kinds of products on the market.

Treating and Controlling Bacterial Infestations

Treating to remove iron will make your water supply more usable, but will not affect down-hole bacteria.

Detecting bacteria early is difficult. To be safe, assume that if your iron concentration is over 0.5 mg/L, your well is inhabited by iron bacteria. Signs of bacterial trouble include a change in color of well water, a decrease in the pumping water level depth, or visual observation of slimes on pump or riser pipe or in household fixtures.

The best controls are preventive and regular well disinfection. Seriously plugged wells will generally need to be serviced by a water well contractor experienced in well rehabilitation. However, "preventive" disinfection is simple and can be done by many homeowners, and for wells that are not badly plugged can prevent further well deterioration. Regularly — one or two times a year, depending on iron level — bacteria-prone wells should be disinfected with a concentrated chlorine solution. First, the volume of water and chemicals required must be calculated by subtracting the non-pumping (static) water level in the well from the well depth. For a 6-inch diameter well, a quart of common laundry bleach and 30 gallons of water per

20 feet of water height should be added to the well, introduced through a rubber hose to the bottom of the well if possible. Half these amounts should be used for a 4-inch well. The well should then be surged vigorously for 15-30 minutes, by starting and stopping the pump intermittently. If there is no check valve on the pump, care must be taken not to start and stop the pump too frequently or the pump could be damaged. Pumped water should be recirculated down the casing. Following surging, more clean water (the same volume added before) should be added and the well allowed to stand without pumping for 12-24 hours. Then the disinfected well should be pumped to waste, by surging again, until the water is clear and the chlorine smell is gone. At least three times the volume of water added to the well should be pumped out, to make sure all chlorine is removed. This waste water should not be pumped onto a lawn or garden, or back into a cistern or pressure tank; it will be undrinkable and can kill grass. This entire procedure can be either done by the individual if he feels knowledgeable working around well equipment, or be done by a pump or well service contractor.

This chlorination procedure should control, if not eliminate, the bacteria in a well. However, they will return; experience shows that a few bacteria outside the well bore survive even the most intensive disinfection. The key to control of iron bacteria is regular well disinfection and removal of iron and organic products. The cost of domestic well replacement is often comparable to and, in some cases, less than rehabilitation of a severely plugged well by a water well specialist. Preventive disinfection is often the well owner's only weapon against iron bacteria.

Another preventive technique is to frequently drop HTH (calcium hypochlorite) pellets to the bottom of the well. One commercially available device, the "Land-O-Matic", is a wellhead-mounted HTH pellet dispenser designed for automatically-timed regular well chlorination. Such low-level chlorination does not restrict growth of bacteria outside the well bore, but may help restrict the growth somewhat in the well. It is not a substitute for periodic shock-chlorination.

Summary

Iron and iron bacterial problems are extensive in much of Montana groundwater, but, if recognized early and treated, can be effectively controlled. For general information on your own well installation or on any of the techniques described here, contact your local county extension agent or the Montana Bureau of Mines and Geology, in Butte or Billings. For special problems in iron removal or well rehabilitation, it is in most cases best to work with an experienced professional in the water conditioning or water well industry. Names of licensed professionals in these fields are available from the Cooperative Extension Service.

Water well contractors and other individuals who do rehabilitation work on wells or are interested in this problem can be placed on the Cooperative Extension Service's list for information by contacting Jeff Jacobsen, Soil Scientist, Cooperative Extension Service, Montana State University, Bozeman, MT. 59717.

Table 2

Representative list of currently-available (1987) iron-treatment equipment for residential well use. No products in this list have been tested or verified to be effective by the author; their inclusion here is only to list representative products typical of their category, for which technical information is available. No endorsement is stated or implied.

Product Name	Treatment Principle	Flow Cap. (GPM)	Manu. Max. Iron Removal Cap. (mg/L)	Oxidant
MacClean	oxidation/ filtration	4-1250	—	air
Kinetico	oxidation/ filtration	3-6	10-15	$KmnO_3$
Watersoft Provectr I	oxidation/ filtration	3-9	20	air
Kinetico Rust-Plus	ion exchange	3-6	50	none
Aqua-Mag	seques-tration	N/A	4	none
Auto-Trol Land-O-Matic	down-well chlorina-tion	N/A	—	Na-hypo-chlorite pellets

The Montana Water Well Drillers Association Meeting will be February 2-5, 1988 at the Holiday Inn West, Billings, Montana. For details contact Kevin Haggerty, 587-2303, Bozeman, or Vicki Lautt, 665-2889, Hardin.

On behalf of the Board of Water Well Contractors and staff, we wish you a Merry Christmas and a good New Year.

For further information on any of the material contained herein contact:

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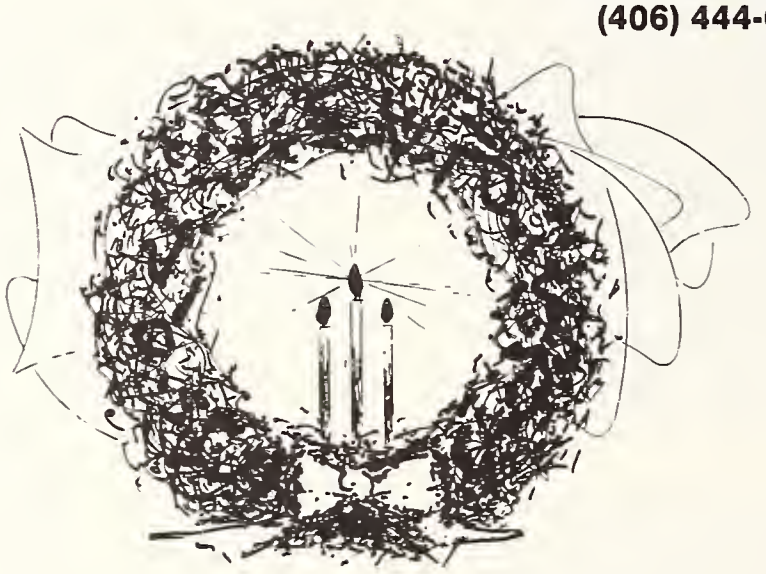

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